Closed reduction and fluoroscopic assisted percutaneous pinning of 42 physeal fractures in 37 dogs and 4 cats

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Abstract: OBJECTIVE: To report complications and clinical outcome of dogs and cats that underwent fluoroscopic-assisted percutaneous pinning (FAPP) of physeal fractures. STUDY DESIGN: Retrospective study. ANIMALS: Client-owned dogs (n = 37) and cats (n = 4). MATERIALS AND METHODS: Records (August 2007-August 2014) of physeal fractures treated with FAPP in 3 hospitals were evaluated. Data collected included signalment, fracture characteristics (etiology, location, duration, Salter-Harris classification, preoperative and postoperative displacement), surgical information (implant size, surgical duration), and outcome assessment information (functional outcome, radiographic outcome, and complications). RESULTS: The majority of animals (92%) were classified as full functional outcome. No significant predictors of functional outcome were identified. The overall complication rate was 15% (n = 6). Elective pin removal rate was 41% (n = 17). Goniometry and limb circumference measurements of the affected and contralateral limbs were not significantly different in dogs for which measurements were obtained. Seventeen of 18 animals (16 dogs, 2 cats) measured had bone length changes on follow-up radiographs. CONCLUSION: FAPP is associated with an excellent functional outcome in a narrow selection of fracture configurations, specifically those with minimal displacement and for which anatomical alignment can be achieved with closed reduction.

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Title Page

Running Head: FAPP of Physeal Fractures

Title: Closed Reduction and Fluoroscopic Assisted Percutaneous Pinning of 42 Physeal Fractures in 37 dogs and 4 cats

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Abstract

Objective: To report complications and clinical outcome of dogs and cats that underwent fluoroscopic assisted percutaneous pinning (FAPP) of physeal fractures.

Study Design: Retrospective

Animals: Client-owned dogs (n=37) and cats (n=4).

Materials and Methods: Records (August 2007- August 2014) of physeal fractures treated with FAPP in three hospitals were evaluated. Data collected included signalment, fracture characteristics (etiology, location, duration, Salter Harris classification, pre- and post-operative displacement), surgical information (implant size, surgical duration), and outcome assessment information (functional outcome, radiographic outcome, and complications).

Results: The majority of patients (92%) were classified as full functional outcome. No significant predictors of functional outcome were identified. The overall complication rate was 15% (n=6). Elective pin removal rate was 40% (n=17). Goniometry and limb circumference measurements of the affected and contralateral limbs were not significantly different in patients which measurements were obtained. Seventeen of 18 patients measured had bone length changes on follow-up radiographs.

Conclusions: FAPP is associated with an excellent functional outcome in a narrow selection of fractures.

Introduction

Physeal fractures are common, constituting up to 30 percent of appendicular fractures in immature dogs.[1] Salter-Harris (SH) types I and II are the most common representing 77 percent of physeal fractures, however sparse reports on surgical outcome measures exist in veterinary medicine.[1] Traditionally, the majority of physeal fractures in dogs and cats have been repaired with open reduction and internal fixation (ORIF). Kirshner wire fixation is commonly used, with different configurations such as parallel, cross, or dynamic pinning.[2,3] Clinical outcome following ORIF has been reported to be good to excellent,[4-7] although lack of physeal function post-operatively can lead to growth abnormalities in some cases.[2]

Fluoroscopic assisted percutaneous pinning (FAPP), a minimally invasive fracture repair technique, consists in closed reduction and internal fixation by Kirschner wires inserted through small skin incisions under fluoroscopic guidance.[8] FAPP is commonly performed in children, with success rates between 68% and 100%, excellent patient satisfaction compared to ORIF, and infrequent loss of reduction compared to external coaptation .[9,10] The advantages of FAPP over ORIF and external coaptation in children are most apparent in the immediate post-operative period with all techniques having similar long-term outcomes.[9,10] Long-term complications following physeal fracture repair in children have been shown to be influenced by age, affected physis, time between injury and surgery, trauma etiology, Salter-Harris classification, and fracture displacement.[11]

The reported outcome of minimally invasive fracture repair in dogs is excellent.[4, 12-14] Short time to healing and low risk of complications have been associated with minimally invasive plating of diaphyseal radial and tibial fractures.[13,14] In keeping with the principles of biologic fracture fixation, alternatives to traditional ORIF of physeal fractures, such as FAPP, should be considered in attempt to improve clinical outcomes. Potential advantages of FAPP include faster patient recovery, decreased pain, decreased infection, and limited iatrogenic trauma to the physis, soft tissues, and surrounding blood supply. Potential disadvantages of minimally invasive fracture repair include less accurate fracture reduction, increased risk of malalignment and increased surgical time.

Veterinary studies evaluating outcome following FAPP are limited. A single veterinary study reported a good outcome with closed reduction and blind percutaneous pinning of femoral and tibial fractures, seven of which were physeal fractures.[15] The reported advantages of fluoroscopy for pin placement for spinal stabilization in dogs include decreased operative trauma, post-operative morbidity, and improved accuracy and safety .[12] Cook et al, reported good outcomes following fluoroscopic assisted percutaneous pin and screw placement for lateral humeral condyle fracture repair in immature and adult dogs.[4] Recently the technique of FAPP for capital physeal fractures and FAPP for physeal fractures was described, however, clinical outcome was not reported.[8,16]

Our objectives were to retrospectively report complications and clinical outcome of dogs and cats that underwent FAPP of physeal fractures. We hypothesized FAPP is a safe and effective technique to facilitate healing of physeal fractures. Safety was defined based on the morbidity associated with the procedure and efficacy was defined as the ability of the technique to return the animal to pre-operative function.

Materials and Methods

Study Population

Medical records (August 2007- August 2014) of dogs and cats with FAPP of physeal fractures without conversion to an open approach in three veterinary hospitals (Animal Specialty and Emergency Center, University of Florida, Georgia Veterinary Specialists) were identified retrospectively. Cases were excluded from the study due to conversion to an open approach. Pre- and post-operative radiographs and complete surgical reports were required for study inclusion. Data collected included signalment, fracture characteristics (etiology, location, duration, SH classification, pre- and post-operative displacement), surgical information (implant size, surgical duration), and outcome assessment information (functional outcome, radiographic outcome, and complications).

Surgical Procedure

The technique utilized by the authors was as previously described by Kim et al.[8] Briefly, manual traction and counter pressure were applied to facilitate closed reduction. Reduction was confirmed with intra-operative fluoroscopy prior to implant placement (Fig 1). Internal fixation with small diameter smooth bone pins through small skin incisions or directly percutaneously was performed in the same manner as pin placement for open physeal fracture repair (e.g. cross pins, parallel pins) depending on the affected physis. Internal fixation was evaluated intra-operatively with fluoroscopy (Fig 1). Surgical duration was defined as the start of closed reduction to removal of the drapes. Intra-operative differences between surgical facilities included the mobile fluoroscopic unit, surgeon experience level, and treatment of the cut pin ends. Surgeons included residents and boarded surgeons. Cut pin ends were countersunk, bent, left long but subcutaneous, or cut as short as possible. Mobile fluoroscopic units included Siremobil Compact Fluoroscope (Siemens, Iselin, NJ), Pulsera (Philips, Andover, MA), and Philips BV3000 (Philips, Andover, MA).

Distal tibial and radial fractures were protected with external coaptation (lateral and caudal splints respectively) until clinical union of the physeal fracture. Clinical union was defined as palpable stability of the fracture repair. Passive range of motion and cold compression was initiated postoperatively in fractures at the level of the shoulder, hip, and stifle. Non-steroidal anti-inflammatory drugs were prescribed for two weeks postoperatively. Activity restriction including cage rest and short controlled walks were recommended. Radiographs were recommended every two weeks to monitor fracture healing.

Functional Assessment

Post-operative rechecks were variable between 1 and 6 weeks until clinical union was achieved. Patients were requested to return for an outcome evaluation following clinical union. Full outcome evaluation included a subjective lameness examination, validated owner questionnaire,[17] objective measurements (goniometry and limb circumference) and radiographs of the affected and contralateral bone. Lameness was graded on a 5 point scale, where 0 is normal, grade 1 is mild subtle lameness with partial weight bearing, grade 2 is obvious lameness with partial weight bearing, grade 3 is obvious lameness with intermittent weigh bearing, and grade 4 is full non-weight bearing lameness.

Goniometry included flexion and extension of the joint adjacent to the fractured physis and the contralateral joint. Goniometry was performed as previously described.[18] Briefly, the center of the goniometer was placed at the joint and the arms of the goniometer along the long axis of the adjacent diaphysis. Limb circumference was only obtained on the hindlimb with a tape measure and was measured at 50% of the length of the femur on the affected and contralateral limb. For those patients that did not return for the full outcome evaluation, owners were contacted and asked to complete the questionnaire. If the owner was unable, functional outcome was determined by phone interview or by the attending clinician at the last recheck examination.

Functional outcome assessment was defined as previously described by Cook et al.[19] Functional outcome was classified as full, acceptable, or unacceptable. Full function was defined as restoration to pre-injury status. Acceptable function was restoration to pre-injury status that was limited in level, duration, or required medication to achieve. Unacceptable function applied to all patients who did not exhibit full or acceptable function. Complications were classified as catastrophic, major, or minor, again as defined by Cook et al.[19] Catastrophic complications were those that caused permanent unacceptable function, directly related to death or euthanasia. Major complications were those that required additional medical or surgical intervention beyond the current standard of care. Some surgeons performed elective pin removal; others performed removal if complications were associated with the pin. Minor complications were those that resolved without additional treatment. All complications and subsequent treatments were recorded.

Radiographic Assessment

Orthogonal radiographs of the fractured bone were obtained pre- and post-operatively and at variably scheduled rechecks. Radiographs of the affected and contralateral bone were obtained using a 10 centimeter calibration marker during the study-related follow-up evaluations. Radiographic assessment included pre- and post-operative displacement grading, fracture healing, and measurement of bone length discrepancy between affected and contralateral limbs.

Pre-operative radiographs were evaluated for physis affected, Salter Harris (SH) classification, and displacement. Pre-operative fracture displacement was graded as previously described by Arkader et al[11] (Fig. 2). Grade 1 was less than 1/3 of the bone width. Grade 2 was 1/3 to 2/3 the bone width. Grade 3 was greater than 2/3 the bone width.

Post-operative fracture reduction was graded based on the presence of a metaphyseal-physeal step. This grading system was based on a scoring system previously described by Cook[4]. Grade 0 was anatomical reduction. Grade 1 was minimal malreduction (<1mm). Grade 2 was moderate malreduction (1-3mm). Grade 3 was severe malreduction (>3mm).Radiographic fracture healing was assessed by radiographic signs (bridging bone seen on both lateral and craniocaudal radiographic projections or loss of physeal lucency), however since the study was retrospective, time to bony union could not be accurately determined due to varied recheck protocols. Complications of bony healing were noted.

Measurements performed on orthogonal radiographs from identical points on the affected and contralateral bones were obtained to evaluate bone length discrepancies.

Only radiographs with a 10 centimeter calibration marker and with identical positioning between the affected and contralateral limb on radiographic review were used to measure bone length.

Statistical Analysis

First, data summaries (means, medians, standard deviations and interquartile ranges) and graphs were used to inspect the data for missing or spurious values and to assess the shape of the variable's distributions. Next, three types of analyses were used to analyze the data, depending on the kind and distribution of the variable. Correlated data (e.g., affected and contralateral bone lengths) were analyzed with paired t-tests. Relationships between binary (e.g., implant removal) and continuous variables (e.g., pin size) were analyzed with nominal logistic regression with ward chi-square tests for the parameters. Relationships between discrete data in the form of contingency tables were analyzed with chi-square tests or Fisher's exact tests. Statistical significance was set at P<.05. JMP 11.2.0 (SAS Institute, Cary, NC) used for statistical analysis.

Results

Study Population

Medical records of 37 dogs and 4 cats with 42 physeal fractures were reviewed. One dog had bilateral tibial fractures. No cases were excluded from the study due to conversion to an open approach. There were 27 males (12 castrated, 15 intact) and 14 females (9 spayed, 5 intact). Mean weight was 10.4kg (median 8.8 kg; range, 1.7-39.6kg). Mean age was 6.9 months (median 6 months; range, 3-18 months). Radiographs revealed open physes, therefore the patient was included in analysis. Fracture etiology included hit by car (8), fall/drop (16), other (4), unknown (13). Fractured physes included proximal tibia (20), distal femur (8), distal tibia (7), distal radius (3), proximal humerus (3), and capital physis (1). Proximal tibial fractures included proximal tibial physis (13), apophyseal avulsions (1), and a combination of both (6). Mean duration of pre-operative fracture duration was 2 days (median 2 days; range 0-8 days). All fractures were SH type I (17) or type II (25). Pre-operative radiographic displacement included grade 1 (26), grade 2(8), and grade 3 (8).

Surgical findings

The majority of fractures were treated with crossed pins (n=32, 76%) with the remainder treated with parallel pins (n=10, 24%) (Fig. 3). Pin number ranged from 2 to 6 (median 2; mean 2.7). Implant sizes ranged from 0.9-2.4 mm (median 1.1 mm; mean 1.3 mm) diameter. Pin ends were bent (9), cut short (6), or left long (27). Surgical duration was reported in 38 patients with a mean of 42 min (median, 30 min; range, 4-119 minutes).

Outcome assessment

Eleven animals returned for the full outcome assessment (contralateral radiographs, goniometry, thigh circumference measurements, validated questionnaire). The other animals had variable follow-up (Table 1). Mean follow-up duration was 16 months (median, 6.3 months; range 25 days-5.7 years). Thirty-seven patients had a reported follow-up evaluation performed by a clinician. Four animals had no follow-up evaluation performed or reported. Thirty-four of the 37 animals had a reported full functional outcome (92%). Three animals had an acceptable outcome (8%). Nineteen animals' functional outcome was reported by the owner in the questionnaire. Of the 19 reported, 17 animals had a full functional outcome, two had an acceptable outcome. The questionnaire results matched with the clinical evaluations. Thirteen animals had goniometry performed. Decreased range of motion (ROM) was noted in 5 of the 13 (median 5 degrees; mean 5 degrees; range 2-10). One dog had increased ROM by 5 degrees in flexion and extension. Four animals had no difference in goniometry measurements. Goniometry measurements of the affected and contralateral limbs were not significantly different (n=13; P=.022). Twelve animals had limb circumference measurements. Decreased limb circumference of the affected limb was reported in six dogs (median 0.75 cm; mean 2.2 cm; range 0.3-9). One dog had an increase of 1 cm in the affected limb. Five animals had no difference in limb circumference. Limb circumference measurements of the affected and contralateral limbs were not significantly different (n=12; P=.024).

Radiographic union was achieved in all cases for which radiographic follow-up was available (n=34). There were no radiographic healing complications. Based on the inconsistent time for radiographic evaluations it was not possible to determine the exact healing time. However, all fractures healed in less than 12 weeks. Eighteen animals returned for follow-up comparison radiographs of the affected and contralateral limbs. Fourteen (78%) had shortening of the affected bone (Fig. 3) and three (17%) had lengthening of the affected bone; those counts are statistically different (P=.006). One (5%) had no change in affected bone length. Bones were shortened or lengthened an average of 5.7% and 1.9%. respectively. Of those with comparison radiographs, 15 had a full functional outcome and 3 had an acceptable outcome. Post-operative fracture displacement included grade 0 (18), grade 1 (14), grade 2 (7), and grade 3 (3). There were no radiographic or clinical outcome measures that were significantly associated with functional outcome.

The overall complication rate was 15% (n=6). Major complications (n=5; 12%) included incisional infection that resolved with antimicrobials (n=1), pin irritation with subsequent removal (n=1), septic arthritis (n=1), and pin migration that required subsequent replacement (n=2). A single minor complication was reported in a dog with a broken pin noted on follow-up radiographs (n=1; 2%). Elective pin removal was performed in 41% (n=17) of cases. Pin end management did not significantly influence outcome and was not a predictor for pin removal on statistical analysis.

Discussion

In the present study of 37 dogs and 4 cats undergoing FAPP of physeal fractures there was an overall complication rate of 15%. Our clinical observations revealed full functional outcome in the majority of dogs (92%) and no significant difference between objective measurements (goniometry, limb circumference) of the affected and contralateral limb. Although most complications were classified as major, they were not life-threatening, and easily addressed without significant patient morbidity.

One of the important findings of the study was the high rate of elective implant removal. The pin ends were managed in different ways, including cut short and countersunk, bent or left long to facilitate removal. However, there was no statistically significant effect of pin end management on implant removal. We are not aware of an established standard of care recommendation regarding elective pin removal following physeal fracture repair in veterinary medicine. We propose to establish a standard of care that includes planification for elective pin removal following physeal fracture repair in small animal surgery.

The pin removal rate for ORIF of physeal fractures is not currently known. Three previous studies on fracture pinning have included a subset of patients with physeal fractures. In 1989, a study evaluating blind pinning of the tibia and femur reported a pin removal rate of 71% in seven physeal fractures .[15] In 2004, Fisher et al reported a pin removal rate of 56% in 16 feline capital physeal fractures.[5] Saglam and Kaya reported that no pin removals were performed in 7 dogs undergoing ORIF of proximal tibial fractures.[6] Arguments have been made in both human and veterinary medicine supporting elective pin removal to prevent premature closure of the physis.[2,16,20]

Most animals included in this study were rechecked by a clinician and had an excellent outcome, based on the restoration to pre-injury status. Despite our results we cannot make valid comparisons between FAPP and ORIF as we did not include an ORIF cohort. In human medicine, comparable long-term outcomes have been reported between open pinning and percutaneous pinning; however, significant improvement in patient satisfaction was reported in children undergoing percutaneous pinning compared to open pinning.[9] Patient satisfaction is difficult to quantify in animal patients, however, we suspect there is decreased post-operative morbidity and greater owner satisfaction with FAPP based on the experiences of the surgeons involved with these cases.

We found a significant difference in length between the affected and contralateral bones in the 18 patients that returned for radiographic comparison, however, it never exceeded 6%. Length change did not significantly influence functional outcome. In the 14 patients that had shortening of the affected bone, we presume this finding was secondary to premature closure of the involved physis. This finding is unexpected because most fractures were SH type 1 or 2, which should carry the best prognosis.[20] Interestingly, three patients had increased length of the affected bone. A single veterinary report describes lengthening of the humeral diaphysis following physeal fracture repair.[21] It was speculated that lengthening could be secondary to decreased stress on the fractured physis or possibly over stimulation of the physis. Future studies evaluating sequential radiographic monitoring of the physis would be necessary to support these speculations in our patient population.

Limitations of this study include those inherent to retrospective, multi-center studies: lack of an ORIF cohort; variations in surgeon skill and technique; modifications of and improvements in the technique during the course of the study; and variable case follow-up. Some intra-operative data variability was likely attributed to surgeon variability and training. Surgeons included both surgical residents and board certified surgeons. Given FAPP is a newer technique; several surgeons were initially unfamiliar with the percutaneous pinning technique resulting in longer operative times and possibly poorer post-operative results. Surgeon was not included as a variable in our data analysis. As a retrospective, multi-center study, we expected a large amount of case variability in the follow-up data. Case numbers declined as more complete follow-up data was obtained.

Most fractures included in the study were minimally displaced, suggesting that preoperative fracture displacement played an important role in the selection of FAPP versus ORIF. In children the distance of fracture displacement is used as selection criteria for choosing between closed reduction and open reduction.[22] In a recent study in 286 children, open reduction was selected in patients with more than 2 mm of fracture displacement, even after closed reduction.[22] Based on our experience, we would recommend FAPP for fractures with minimal displacement. In addition, we would consider FAPP only if anatomical alignment could be achieved with closed reduction. Post-operative fracture displacement did not influence patient outcome. In human literature, the presence of displacement has been associated with increased complications in children with distal femoral physeal fractures. Additionally, increased displacement has been correlated with an increased likelihood of complications.[11]

Based on the overall results of this study, FAPP is a safe procedure associated with a high elective pin removal rate and an excellent final functional outcome.

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Disclosure

The authors report no financial or other conflicts related to this report.

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Figure Legend

Figure 1: Intraoperative fluoroscopic images (A, B), postoperative (C) and 4-week recheck (D) radiographs of a 7 month-old mixed breed dog presented with a grade 1 (displacement grade 1=minimally displaced, grade 2=mildly displaced, grade 3=severely displaced), proximal tibial physeal fracture (Salter Harris type 1). The fracture was reduced by extending the stifle and applying traction using bone reduction forceps (A). A 2 mm K-wire was inserted through the tibial tuberosity to stabilize the fracture. Then, additional 2 mm K-wires were inserted medially and laterally (B).

Figure 2: Representative radiographs of three animals with grade 1 (<1/3 bone width displacement), grade 2 (1/3 to 2/3 bone width displacement) and grade 3 (>2/3 bone width displacement).

Fig. 3: Preoperative (A, B), postoperative (C, D) and 1 year recheck examination (E, F) radiographs of a 8 month-old Jack Russell Terrier presented with a grade 1 (displacement grade 1=minimally displaced, grade 2=mildly displaced, grade 3=severely displaced), distal femoral physeal fracture (Salter Harris type 2). The fracture was reduced using manual manipulation and 1.5 mm K-wires were inserted percutaneous distal-to-proximal. No growth abnormalities were detected at 1-year recheck examination (E, F).

Fig. 4: Preoperative (A, B), postoperative (C, D) and 2-year recheck examination (E, F) radiographs of a 9 month-old mixed breed dog presented with a grade 3 (displacement grade 1=minimally displaced, grade 2=mildly displaced, grade 3=severely displaced),

proximal humeral physeal fracture. The fracture was reduced using manual manipulation and 1 mm K-wires were inserted percutaneous proximo-to-distal. Mild rotational malalignment was noted in the postoperative radiographs (C, D). Shortening was detected at 2 year recheck examination (E, F), but excellent function was reported by the owner.

Tables

Table 1 Variability in Patient Follow-up

Description of Follow-up	Number of patients
Full (E, CR, G, Q)	11
E	1
E, P	4
E, R	11*
E, CR	5
E, R, P	2
E, CR, Q	1
E, CR, G	1
E, R, Q	3
No follow-up	2

E, exam; CR, contralateral radiographs; G, goniometry; Q, validated questionnaire; P, phone; R, follow-up radiographs

* Includes dog with bilateral procedures